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Analyzing Comparative Advantage of Agricultural Production and Trade Options in Southern Africa: Guidelines for a Unified Approach

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Foreword

Southern Africa was characterized by a heavily regulated agricultural market before the late 1980s but, since then, countries in the region have followed a strategy to remove restrictive measures from the agriculture sector. The deregulation process has occurred in the context of worldwide liberalization of agriculture. These changes mean that all the countries in the southern African region have to compete internationally in a more open agricultural market. In order to be competitive, southern African countries will have to use resources more efficiently by exploiting comparative advantages that may exist. This, among other things, entails that policy and decision-makers should be guided so as to implement policies and strategies that will enhance the competitiveness of agricultural producers.

Various studies have shown that countries can improve their welfare by opening up their borders to freer trade. Furthermore, there is a worldwide move toward economic integration; the European Union being one prominent example. Southern Africa is no exception with the movement toward a Free Trade Area under the auspices of the Southern African Development Community (SADC). Not only is it foreseen that this movement will improve welfare in the whole region, but the region's competitiveness could also improve. Within the framework of economic integration in southern Africa, countries will only reap benefits by exploiting comparative advantages within the region.

Seven countries in SADC are participating in the Research Program on Regional Agricultural Trade and Changing Comparative Advantage in Southern Africa. This document develops the unified analytical framework and guidelines for the comparative economic analysis (CEA) studies of the seven countries. These studies do not only examine the existing comparative advantages, but also provide a means to evaluate the impact of different agricultural policies on comparative advantage. This proves to be an especially valuable tool to guide policymakers in the region. The focus of this particular document is on the operational aspects of implementing CEA analysis with special emphasis on the use of spatial analysis and geographic information systems (GIS) tools to conduct CEA analysis within an agro-ecological zone framework.

This study is one in a series of studies on Africa's regional trade and comparative advantage, a joint activity of USAID Africa Bureau's Office of Sustainable Development, Agriculture, Natural Resources, and Rural Enterprise (ANRE) Division and the Regional Economic Development Services Office for Eastern and Southern Africa (REDSO/ESA).

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Dedication

Dedicated to the memory of the late Professor Glenn Themba Magagula, formerly Deputy Vice Chancellor of the University of Swaziland, whose vision, foresight and leadership led to the development and implementation of the "Regional Trade and Comparative Economic Advantage in Southern Africa" activity.

Analyzing Comparative Advantage of Agricultural Production and Trade Options in Southern Africa: Guidelines for a Unified Approach

INTRODUCTION

A new political and economic environment is emerging in southern Africa (SA) with the admission of the Republic of South Africa to regional trade and economic activities. Bilateral as well as regional initiatives and negotiations are already underway to promote regional economic integration and cooperation through liberalized trade and fair competition in commodity markets. In general, the ultimate goal of the ongoing efforts is to extend the current preferential trade arrangements to establish a regional trading block and a common market for eastern and southern Africa (COMESA). These efforts are expected to lead to significant changes in economic policy and trade regimes, which in turn will have significant implications for the regional economy, especially in the production and exchange of agricultural commodities, and consequently national and regional food security. Coupled with the worldwide drive toward freer trade, these regional initiatives are expected to hasten economic policy reforms in the region in the direction of reduced protection and elimination of tariff and non-tariff barriers to cross-country movement of goods and services.

There is ample evidence that all countries in the SA region impose high tariff and quantitative (non-tariff) restrictions on imports, mainly to protect infant industries and subsidize domestic food production for food security and reduced reliance on food imports. That means, policy reforms aimed at dismantling protectionist measures will no doubt result in significant reductions in the magnitudes and extent of distortions in relative prices caused by such measures. As free trade will direct productive resources to their best uses on the basis of economic efficiency principles, the resulting change in the structure of economic incentives is bound to induce major adjustments in the patterns of production, allocation of resources and trade flows between countries involved. It is therefore crucial for every country to understand and exploit its comparative advantage in the production and trade of agricultural commodities. The Regional Agricultural Trade and Changing Comparative Advantage in SA project has accordingly been initiated to generate results in research analysis and policy information on this important aspect of the unfolding new economic order in the region.

Under the overall objectives of the project, a number of country studies were commissioned to conduct the intended analysis. Country-level analyses are carried out by country research teams of multi-disciplinary composition assisted by technical backstopping and research logistical support from CARPA, University of Swaziland. One important objective of the country studies is to generate data on agricultural production and trade parameters that will feed into a regional database to support further synthesis of the above discussed aspects at a regional scale. Therefore, it was considered essential for all country studies to adopt a unified approach and methods in order to ensure the consistency of country components of the regional database. The present document develops the unified analytical framework and guidelines for the standardization of methodology in key areas. This report complements the review of the theoretical foundations and methods of Comparative Economic Advantage (CEA) analysis and trade prepared for this same project by Masters (1995). The focus of the present document is, however, is on the operational aspects of implementing CEA analysis with special emphasis on the use of spatial analysis and geographic information systems (GIS) tools to conduct CEA analysis within an agroecological zonation framework.

OBJECTIVES OF THE STUDY

The main objective of this regional project is to conduct comprehensive analysis of the CEA of alternative productive uses of agricultural resources in SA and evaluate potential changes in production and trade patterns in response to expected changes in the economic policy environment. Under the overall objectives of the project the present report attempts to develop a unified approach and analytical framework for country studies to achieve the following specific objectives:

1. Evaluate the CEA of alternative agricultural production activities in the various agroecological zones and under the different technology levels and land tenure systems in the country.
2. Analyze the potential impacts of removing existing price and policy distortions in the structure of economic incentives on the economic efficiency of alternative productive uses of the country's resources.
3. Identify points of policy, technology, and institutional interventions to enhance economic efficiency and direct agricultural resources to their most productive uses.
4. Build country data components needed for conducting the regional analysis of CEA and trade in agricultural commodities for SA.

METHODS AND ANALYTICAL FRAMEWORK

CEA evaluates the economic efficiency of alternative productive uses of the scarce land, labor, capital and water resources. The option that generates the highest social gains from the use of domestic resources is considered the most efficient user of those resources. Domestic Resource Cost (DRC) analysis techniques are commonly used for measuring CEA. For any production option to be the most efficient user of the country's resources, two conditions are to be met:

a. First, the foreign exchange cost of the domestically generated product must be less than its import price, i.e., it costs less to produce locally.
b. In addition, the net foreign exchange gain from producing that product must exceed the net economic gain foregone from using the same amount of domestic resources to produce alternative products (or the same product under a different technology or production system), which is referred

Table 1. Measures of Economic Efficiency and Policy Distortions.

	Tradable Products	Inputs	Non-traded Domestic Resource
1. Value at market prices	MP	MR	Y
2. Value at social prices	P	R	N
3. Policy effect (tax/subsidy)	MP-P	MR-R	Y-N
4. Net private profitability	NPP =	MP - MR - Y	
5. Net social profitability	NSP =	P - R - N	
6. Nominal protection ratio	NPR =	MP/P	
7. Effective protection ratio	EPR =	(MP-MR)/(P-R)	
8. Total net policy effect	NPE =	PP - SP	
9. Value added	VAD =	P - R	
10. DRC ratio	DRC =	N / (P-R)	

Source: Adapted from Monke and Pearson (1989).

to as the opportunity cost of domestic productive resources.

Measures of economic efficiency include Net Social Profitability (NSP), Value Added (VAD), DRC and Resource Cost Ratios (RCR). Various policy interventions and market failures cause market prices of traded commodities and non-traded goods and services to diverge from their social values (true economic value or cost). Such policy interventions distort the structure of economic incentives in favor of certain production activities and hence discriminating against others for non-efficiency purposes (equity, low food prices, protection of local industries, etc.). This leads to inefficient allocation of resources and non-optimal production and trade patterns (e.g., over or under production of certain goods and over use of a domestic resource). For more accurate prediction of the nature and direction of likely changes in resource use, production and trade patterns as such policy distortions are removed, it is important to understand and quantify their impacts on relative prices and structure of incentives. The Policy Analysis Matrix (PAM) offers an appropriate framework that is widely used to evaluate the extent of policy distortions. Commonly used measures of CEA and policy distortions are summarized in Table 1[1]. This project will adopt the PAM framework and DRC methodology to derive the above measures of CEA and achieve the set of objectives listed above.

DETERMINANTS OF CEA

Several factors determine CEA. Among the most important determinants of CEA in agriculture are the following:

a. Biophysical conditions. These include the physical climate (rainfall, temperature, number and length of sunny days, etc.); physical and chemical soil characteristics; terrain; etc. Being a biological process, the importance of these factors to agriculture is evident as they determine the biological potential (yield) and suitability of agricultural production activities.

b. Level of technology and production systems. All farming activities are practice under modern and traditional methods and in various scale, land tenure, and cropping systems. The yield potential as well as net economic gains from farming vary significantly with variations in these factors. For example, higher yields are usually realized under irrigation and mechanization. However, given the high costs associated with modern methods of production, certain products may generate higher economic margins under low input agriculture.

c. Prices. Regional as well as international demand and supply forces determine market prices and hence the costs and value of traded outputs and inputs.

d. Markets and infrastructure. Proximity to major consuming centers (markets) may be a key determinant of CEA, especially when transportation costs are high or the road infrastructure is poor.

e. Resource endowments. The relative abundance or scarcity of productive resources such as land, water, labor, etc. determine their availability and hence their relative costs or value. Labor intensive activities, for instance, will have a disadvantage in labor scarce countries.

f. Economic policy. Market-oriented economic systems promote competitive economic advantage by attracting productive resources to their most profitable uses. Governments intervene in the economic arena to control economic activities in pursuit of social goals, such as equity and food security. Economic efficiency objectives often conflict with the cause for social justice and environmental health. It is therefore, a common case that such policies distort the structure of economic incentives against economic efficiency leading to sub-optimal allocation of resources. Taxes and subsidies, for instance, take various forms ranging from an overvalued currency to protect domestic industries (e.g., Republic of South Africa pre-liberation), a subsidy on agricultural inputs to support small holders and direct subsidies to food

For further details see Masters (1995) and Monke and Person (1989) prices in support of the poor. As a result, the principle of CEA fails to guide resources to their economically most efficient uses.

In order to capture and analyze the impacts of the described determinants, measures of CEA and policy effects will be calculated for various agricultural production activities. The following convention will be adopted to define alternative production options to compare and reflect the influences of the above factors:

1. As recommended by the project's steering committee in its meeting of June 1996 in Pretoria, the agroecological zonation approach will be adopted as the framework for classifying production environments to control for the effect of diversity in biophysical conditions.
2. Variations within agroecological zones (AEZ) due to variations in technology, tenure, etc. will be captured by coding every production system as a distinct activity (see example below).
3. Variations in market and infrastructural factors will be reflected in prices and transportation costs. These variations will be captured by defining a central market node for every zone at which all trade will be assumed to take place. Consequently, prices and transport costs between these market centers (nodes) will reflect the opportunity cost of producing a commodity locally versus importing it from another region/zone or from outside the country.
4. Variations in resource endowments will be reflected in the relative rental values of those resources in the different market centers.
5. Policy distortions will be captured by measuring the divergence between market and social prices of goods and services on the input and product sides.

A hypothetical example is developed on the next page for illustration.

Table 2. Representation of the Productive Resource Use Options in the Given Example.

		ZONE 1		ZONE 2		ZONE 3	
		IRRIGATED (IRG)	DRY LAND (DRY)	IRRIGATED (IRG)	DRY LAND (DRY)	IRRIGATED (IRG)	DRY LAND (DRY)
MAIZE (M)	BEST PRACTICE (B)	–	M1BDRY	M2BIRG	M2BDRY	M3BIRG	–
	LOW INPUT (L)	–	M1LDRY	M2LIRG	M2LDRY	M3LIRG	–
MILK (D)	BEST PRACTICE (B)	–	D1BDRY	D2BIRG	D2BDRY	D3BIRG	–
	LOW INPUT (L)	–	D1LDRY	D2LIRG	D2LDRY	D3LIRG	–
COTTON (C)	BEST PRACTICE (B)	–	C1BDRY	C2BIRG	C2BDRY	C3BIRG	–
	LOW INPUT (L)	–	C1LDRY	C2LIRG	C2LDRY	C3LIRG	–

Assume a country has a potential for producing three commodities: maize, milk, and cotton in three AEZ: 1, 2, and 3. The three commodities can be grown under rain fed conditions in two zones (1, 2) or irrigation in two zones (2, 3). Two levels of technology are available: best practice (modern) and low input systems for all. Factors can be as many as one wants. However, the number of options to compare will multiply geometrically as a result, and hence one may want to consider only the most important factors. This example is represented in Table 2. The naming convention adopted for coding the described options in this example is as follows:

a. First character to denote enterprise name, e.g., M for maize, D for milk/diary, and C for cotton.

b. Second character (numerical) to denote zone number.

c. Third character to denote technology level, e.g., B for best practice and L for low-input.

d. Last three characters indicate whether the enterprise is produced under dry land (DRY) or irrigated (IRG) farming systems.

According to Table 2, production of maize (M) in zone 1 under best practice (B) in dry land conditions (M1BDRY) will compete with the following options:

a. Use the resources of zone 1 to produce maize under low-input dry farming (M1LDRY), or

b. Use the resources of zone 1 to produce other commodities and import maize from zones 2, or 3 where it is produced under either of the following systems: M2BDRY, M2BLDRY, M2BIRG, M2LIRG, M3BIRG, M3LIRG, or

c. Import maize from outside the country, and devote the land in zone 1 to either: D1BDRY, D1LDRY, C1BDRY, C1LDRY.

Accordingly, transport costs, taxes, etc. between the border and point of production/consumption inland as well as between trading zones within the country must be added/subtracted to arrive at the value of the commodity at different market centers. Trading points or nodes in this case will be the market centers identified to be central at each zone.

GUIDELINES FOR DATA NEEDS AND GENERATION OF PARAMETERS

A. Construction of Enterprise Budgets.

The first step in parameterizing the rows of the PAM given in Table 1 is to compile enterprise budgets. For every production alternative in Table 2, a budget of costs and revenue must be constructed. Two types of data are needed in developing enterprise budgets: technology parameters (input-output coefficients) and nominal variables (prices). Technology coefficients should be derived separately from nominal values to allow for easy updating and sensitivity analysis as prices change while the production technology structure remains unchanged. Accordingly, production coefficients measuring units of input needed to generate one unit of output should be calculated in separate sheets (e.g., tons of output per ha; man days and kilograms of fertilizer or seed per ha or unit of output). Nominal data parameters such as prices of output and inputs, wage rates, exchange and interest rates, land rents, etc. are also compiled in separate sheets. The two data sets can then be combined to calculate enterprise budgets. For instance, man days/ha multiplied by the wage rate to compute labor costs per ha, yield/ha multiplied by output price to derive revenue per ha, etc. (see Table 3). This allows for evaluating the robustness and sensitivity of the results to changes in relative prices of key variables such as the fertilizer/output price ratios, relative output prices, etc. (see Hassan and Faki 1993).

Fixed costs such as depreciation of equipment, machinery, etc. should be calculated. In many cases when such services are hired, the rental value includes a provision for asset depreciation. However, for an owner-operator situation, operating costs alone underestimate the total cost of the service and hence some way of accounting for capital depreciation would need to be used. Related to the task of estimating capital costs is the fact that some inputs and activities are indivisible (e.g., irrigation, maintenance costs, fixed farm capital such as physical structures, etc.). Appropriate methods for allocation of such costs among production activities need to be sought.

B. Private and social prices.

Market prices at which factors, inputs, and products are traded, often deviate from their true economic values due to a policy distortion introduced as a result of a tax, tariff or a subsidy scheme or a price setting mechanism. CEA analysis is based on the social (economic) values of resources and products, and hence all market distortions need to be calculated and accounted for. Market (private) prices are the prices reported in the market center (node) of the zone in question for traded and non-traded domestic resources.

1. Traded goods

Social prices for traded goods and services are established based on import/export parity prices converted at the equilibrium exchange rate with port handling and transport costs to the target market added or subtracted. Data on border world prices is usually easily available. However, whether the export or import parity price is used depends on the scenario of the intended analysis. If the question under investigation is to determine whether producing a certain commodity domestically will be more efficient (cheaper) than buying the same commodity from the world market (as an import substitute). Import parity is the relevant price. When the question pursued in the analysis is whether a particular local production option will be competitive in the world market (e.g., generates an economic surplus over the cost of purchased inputs and opportunity value of domestic resources used), the export parity prices are applicable. Differences in product quality need to be taken into consideration, e.g., imported grains compared to locally produced grains in terms of milling and baking qualities and tastes.

The biggest challenge in establishing social prices of traded goods is the determination of the true economic value of the national currency (exchange rate). This is mainly because the foreign exchange market and capital accounts in most countries are at least partially controlled under fixed or managed exchange rate regimes. As a result, parallel foreign exchange markets emerge with a high premium over the official exchange rate. Recently, most countries in the SA region began liberalizing foreign exchange markets leading to some convergence between official and black

Table 3. Construction of Enterprise Budgets.

	Units/ha	Price/unit		Total cost/value	
		Market	Social	Market	Social
Categories	A	B	C	A*B	A*C
Output (Yield in tons)					
Operation/Input					
Machinery services-fixed (hrs)					
Machinery services-variable (hrs)					
Combine harvesting-fixed (hrs)					
Combine harvesting-variable (hrs)					
Irrigation-fixed (cu m)					
irrigation-variable (cu m)					
Labor-unskilled (hrs)					
Labor-skilled (hrs)					
Purchased inputs					
Seed (kg)					
Fertilizer (kg)					
Livestock feed (kg)					
Etc.					
Land (ha)					
Capital (currency)					

market rates. However, there are cases where the liberalization is still partial or incomplete and the ruling exchange rate still reflects currency overvaluation. It is therefore, crucial to carefully consider such factors in choosing the shadow price of the currency to use to convert import/export parity prices for tradable goods. A number of situations and determination methods exist:

i. The ruling official exchange rate is used as the true economic price of the currency in the case of fully liberalized foreign account and flexi exchange rate regimes where the exchange rate is entirely market determined.

ii. In the case where the foreign exchange market is partially controlled, a number of alternatives are available as documented in several empirical trade and macroeconomic policy analysis studies. The parallel market rate is generally used when such a market exists. However, in many instances dealing in foreign exchange outside the formal banking channels is illegal and involves a high risk of severe punishment. In such situations the parallel market rate overestimates the true exchange value of the currency by sometimes a high risk premium which needs to be corrected for. Other alternatives include the use of Purchasing Power Parity (PPP) for a basket of currencies of major trading partners and equilibrium exchange rate calculations (Elbadawi 1992; Cottani et al. 1990; Edwards 1990).

2. Non-traded resources

If there is adequate evidence that domestic resources such as land, labor, capital and water are traded in competitive markets, then ruling market prices can be used to reflect the true economic value of the resource. In many instances however, markets for these resources either do not exist or are so imperfect that market rental values do not reflect the true economic value of these resources due to several policy distortions. Examples are controls on the transfer of title to land, subsidized rural credit, minimum wage rate policies, etc. In those cases a social price reflecting the economic value of the resource (opportunity cost) needs to be established. Some commonly used approaches to determining true economic values of domestic resources in absence of competitive markets (presence of policy distortions) are briefly outlined below.

i. *Capital*. Interest rates charged by commercial banks are sometimes used as the opportunity cost (economic value) of capital. These are often considered high for agriculture as rates of return to investment in agriculture are, in general lower than commercial urban lending rates for business and manufacturing. Rates charged by informal rural money lenders represent another alternative. Again, informal money market rates are also considered relatively higher than competitive market rates due to situations of discriminating monopolies and other imperfections in rural credit markets. Most informal village lending mechanisms come as a whole package of agricultural services that include input supply and output marketing arrangements with money lenders usually combining a number of other economic functions (e.g., village traders). It is therefore important to correct for such premiums when using these rates.

ii. *Labor.* In many places the labor market is considered competitive and the ruling wage rate reflects the opportunity cost of labor. There are situations, however, where there are imperfections in the labor market leading to deviations in the wage rates from their equilibrium values (wage control and labor regulation policies, public employment, such as in state or cooperative farms, etc.). Urban market wages are often used as a proxy to rural wages. Urban labor markets are similarly not free from policy distortions (minimum wage policy, etc.) and hence require appropriate adjustments.

    Rural wages are also very complex due to functional rigidities and the division of labor between women, men and children and the different agricultural production tasks (e.g., land preparation, weeding, irrigation, harvesting) which require different skills and hence command different wages. Moreover, seasonal variations in availability and demand for labor due to the seasonality of agricultural production activities lead to different wage rates (e.g., peak demand seasons such as harvesting). It is also very common that community labor is organized in cooperative village systems where only in kind expenses are incurred (provision of food and drinks) and participating community members are paid back indirectly through free community labor on their farms. The treatment of family labor adds to the complexity of farm work given the different skill and motivation of family members compared to hired hands. In addition, most farm wages include in kind payments in the form of food or some produce. All the said factors need to be corrected for determining the true economic value or cost of agricultural labor. The argument for zero opportunity cost of labor in situations of relative abundance and high unemployment is seriously challenged.

iii. *Land.* Land rents are used when competitive leasing and hiring of land is observed. This however, is the exception as agricultural land markets are in many places missing or imperfect. The most common practice in determining the true economic value of land is the calculation of the profit margin on the production activity in question as an estimate of returns to land (and managerial acumen) to use as the opportunity cost of land.

vi. *Water.* Irrigation water is often provided at highly subsidized prices. In the case of irrigation, it is preferable if the true economic cost per unit of water delivered is estimated. Some argue for the use of marginal rather than average cost pricing which will achieve more than cost recovery. Water delivery costs should reflect the cost of capital investments made in addition to maintenance and operating costs. Nevertheless, cost recovery principles only capture financial costs but do not reflect the scarcity value of water. This is especially important when water is a scarce resource and many high value uses compete for it. The opportunity cost of water can be established as the net returns foregone in the best use option. There are other alternatives for estimating the true economic value of water. Willingness to pay for water is sometimes observed in actual markets such as the case of village water vending. The opportunity cost of labor time spent on fetching water is another alternative.

C. Trend Versus Current Parameter Values and Sensitivity Analysis

Current prices and values of other parameters (e.g., yield) may not be representative as a result of an atypical production season (e.g., drought, etc.) or an abnormal trading year. Various approaches are used to correct for such situations. The use of an average value over the most recent years (e.g., past five years) rather than using a single period value is a common practice. A more appropriate alternative is to estimate a long-term trend in the values of key parameters such as world prices and use as the base scenario. Sensitivity analysis is then performed over a range of possible deviations from the estimated trend line to test the validity and robustness of results in response to variations in value of key determinants. See Hassan and Faki (1993) for more discussion and examples of sensitivity analysis.

D. Non-Tradable Components of Traded Goods

It is necessary to distinguish tradables from non-tradables. All goods and services that can be moved and traded between markets are generally considered tradables, examples are: outputs, purchased inputs, contract and hire services of labor and machinery, etc. In general, land, water, transport and construction services are considered non-tradables (home goods). However, there is always a non-traded component in tradable goods and services, such as the value of irrigation water, transport and physical structures' services, etc. Many authors estimate the percentage share of non-tradables in the value of traded goods and services and then add that to the cost of domestic resources in calculating DRC and RCR (Corden, 1966; Monke and Pearson, 1989; Hassan and Faki 1993).

E. Number of Feasible Alternatives in the CEA analysis

The total number of options to include in the CEA analysis is a multiple of the factors described above as determinants of CEA. In other words the total number of alternatives = number of zones x number of technology levels x number of production systems x number of enterprises x . . . etc.

It is therefore, important to minimize the number of categories to include to avoid ending with an unmanageable number of options to compare. For instance, in its June 1996 meeting, the project steering committee suggested that 15 enterprises are to be included in the analysis. Combined with two production systems and two technology levels, this will result in 60 alternatives for every zone (15x2x2), which in turn multiplies into 300 options for a five agroecological zonation scheme. However, not all of the 15 enterprises will have a high potential in all the zones. Similarly, not all enterprises are produced or has a potential under all systems and technology levels. For instance, many crops such as sugar cane, cotton, and horticultural commodities will have a potential in dry areas (arid and semi arid environments) only under irrigation. Some judgement, based on objective information (research results on climatic suitability or yield potential, etc.) will need to be made to limit the number of alternatives in the analysis. The following suggestions are offered to help guide such type of decision making:

i. Limit the number of agroecological zones to the maximum of six. This means that zones that are very similar may be grouped together.

ii. Limit the total number of enterprises under the same technology level within a production system in the same zone to a maximum of five. In other words, not more than five enterprises grown under irrigation with best practice in the same zone. The same applies to dry land farming with best practice, irrigation with low-input, dry land with low-input within the same zone. Nevertheless, one may end up with all 15 enterprises considered within every zone, but not all of them for every technology level and production system.

iii. Limit the number of technology levels to the maximum of three (preferably two).

iv. Unless there is a very good reason to add a third option, limit number of production systems to irrigated and dry land only.

v. In most cases technology level will reflect the effect of scale and hence there might not be a good reason to subdivide further based on farm size. However, some large-scale farmers may use low-input technology while some small holders may use best practice, in which case one may need to distinguish by size if that will make any difference at all. This is because usually scale influences access to resources such as land, water, and credit and hence the affordability of modern technology and purchased inputs, causing variations in the level of technology used.

vi. Potential. While some production options (enterprises), production systems (e.g. irrigation) or technology types or levels(use of modern inputs and research recommendations, e.g., improved seed and fertilizers) are currently not practice, they are important to consider for policy analysis purposes. Current practices sometimes reflect the potential. For example, large-scale commercial farmers using modern methods and achieving high yields (best practice option) may be at the production frontier. On the other hand, in the case of small-holder agriculture, the following options can be used to define the potential:

   1. Yields attained by the segment of farmers using improved methods (modern variety, fertilizer, etc.)

   2. Experimental research results when available. Tested new technology, method, crop, etc. One can assume partial achievement factors (50%, 60%, etc.)

   3. Crop simulation models and GIS supported crop yield potential models - based on research findings (see section below on the application of GIS to CEA analysis)

F. Composition of the Research Team

A multi-disciplinary research team is recommended. The following disciplines are expected to have an input into the analysis:

1. Economics, especially agricultural economists;
2. Geography and GIS;
3. Applied physical sciences such as agronomy, crop and animal production; and
4. Policy makers and resource planners.

The following institutions are potential users and collaborators in this analysis:

1. Universities,
2. Agricultural research institutes,
3. Development and economic planning agencies, and
4. Trade and policy research agencies.

The research team is therefore expected to reflect the above disciplines and institutional representation in its composition.

THE USE AND APPLICATION OF GIS AND SPATIAL ANALYSIS TOOLS FOR CEA RESEARCH

Although many spatial factors are important determinants of CEA, spatial dimensions are usually ignored or inadequately incorporated in typical CEA analysis. This is particularly important for agriculture, being essentially a biological process that is highly dependant on biophysical factors. The biophysical environment is a key determinant of the biological potential in agriculture as it influences plant and animal adaptation, growth and development and determines the extent and severity of biotic and abiotic stress elements. However, the influences of spatial diversity in biophysical conditions on agricultural production are in general not systematically incorporated in CEA analysis models.

The spatial frame within which CEA analysis is usually conducted is based on political boundaries or some arbitrary zonation of regions. While political boundaries capture variations in economic and policy attributes, as most of that data is generated and organized on political boundary basis, they are irrelevant for describing variability in biophysical conditions. Influences of agroclimatic diversity on the production potential are alternatively accounted for through inherently deficient treatment in CEA studies. For instance, average yield levels under different technologies and production systems are typically estimated from survey or experimental data and used as economic (technology) variables. This is certainly not a perfect substitute for the more systematic spatial framework that adequately describes the interface between agriculture and the biophysical climate.

Recent advances in manipulation of digital spatial databases using GIS techniques has enabled researchers to more efficiently characterize spatial diversity in biophysical and other attributes. GIS and spatial analysis tools also provided a powerful framework for integrating data on aggregate economic phenomena, as well as, micro level information from field surveys to conduct analysis on the joint behavior and interdependent movements of economic and spatial variables. Economic data such as distribution of population, markets, prices, transport infrastructure, land-use under various production activities, patterns of trade flows and many other attributes can easily be spatially described. Similarly, with geo-referencing through global positioning system (GPS) devices survey data can now be readily integrated into spatial databases (see Hassan 1998). Examples of some applications of these new tools and methods of spatial analysis of direct relevance to CEA analysis are given in the following sections. Appendix 1 describes types of support provided by the project management to enable country research teams to use and apply GIS data and spatial analysis techniques.

A. Delineation of Agroecological Zones to Characterize Spatial Diversity in Production Environments

The tropical regions of the world lie within the tropics of Cancer and Capricorn (23^0 $27'$ N and S). The subtropics are more difficult to define, but are the transition zones caused by altitude and latitude differences between temperate and tropical areas (Kretschmer, 1978).

SA is situated just south of the equator, containing the tropic of Capricorn and extends to southerly latitudes (34^0) where winter rainfall is experienced. This climatic variation is further complicated by the influence of both the Atlantic and Indian oceans, localized differences in altitude, aspect, slope, photoperiod and atmospheric pressure gradients. Furthermore, the southward extension of the East African coastal plain effects perhaps the most southern extension of the true tropics in the world.

The following question arose: how does one deal with the climatic variation of SA when involved in determining functional plant production zones for agriculture?

General global and local climatic classifications (Köppen, 1931; Thornthwaite, 1948; Jackson, 1951) have limited value for predicting specific genotype x climate interactions (Nix, 1983). This type of climatic classification does not satisfactorily deal with the complexity of climatic variation. Other approaches have concentrated on the relation between broad vegetation and climate patterns (Acocks, 1975; Low & Rebelo, 1996; Walter, 1983). Respectively, these authors looked at African continental and South African vegetation from an agricultural potential and biodiversity conservation point of view.

To determine agroecological zones for the project that fit the concept of plant functional production zones and for general utility, the regions were related to the following major international climatic regions:

- **Dry tropical:** rainfall is low, highly variable and seasonal with a distinct dry season. The occurrence of frost is very rare. Humidity is low and day temperatures are high even in winter. Low input cropping does occur but the dry tropics are, in general not suitable for dryland high input crop farming.
- **Moist tropical:** rainfall is average, variable and seasonal with a distinct dry season. The occurrence of frost is very rare. Humidity is often high in summer and day temperatures are high even in winter. Dryland cropping does occur.
- **Humid tropical:** rainfall is high, variable and not distinctly seasonal but with lower frequency during the winter. Frost does not occur and humidity is high. The climate is suitable for tropical crops, e.g., sugar cane.
- **Dry subtropical:** rainfall is low, highly variable and distinctly seasonal. Winter minimum temperatures can be low and frost occurs. Summer day temperatures are high. High input dryland crop yields are often at risk.
- **Moist subtropical:** rainfall is average to high, variable and distinctly seasonal. Winter minimum temperatures are often low and frost occurs in inland areas. Summer temperatures are high.
- **Dry temperate:** rainfall is low to average, variable and distinctly seasonal. Winter minimum temperatures are low and severe frost occurs. Summer day temperatures are high.
- **Moist temperate:** rainfall is high, distinctly seasonal and often variable. Winter minimum temperatures are low and severe frost occurs. Summers day temperatures are mild.
- **Alpine:** similar to moist temperate regions except for lower mean maximum temperatures and rainfall is not as distinctly seasonal
- **Cold desert:** rainfall is very low and very variable. Winter minimum temperatures are very low, and minimum temperatures during summer are cool. Day temperatures during summer very high.
- **Warm desert:** rainfall is extremely low and very variable. Minimum temperatures during summer and winter are higher than in the cold desert
- **Mediterranean:** rainfall varies considerably but occurs primarily in winter. Summer maximum temperatures are high
- **Maritime:** rainfall is average to high with uniform distribution. Temperature variation (day/night; summer/winter) is less pronounced than in other regions of SA.

The use of this climatic classification (Table 4) for the determination of agroecological zones was based on the following generalized assumptions:

- The optimum temperatures for photosynthesis in tropical and temperate species are $30/15^0$ C and $25/10^0$ C, respectively (Voisin, 1961).
- Mean temperature at the same latitude is 1^0 C cooler for every 100 m increase in altitude.
- At the same altitude, mean temperature decreases by 1^0 C every 100 km further south of the Tropic of Capricorn.

Table 4. Rainfall and Temperature Criteria Used for the Classification of Agroecological Zones for Southern Africa (Loosely Following the Koppen Climate Classification System)

	Rainfall (mm)		Temperature: Coldest Month		Rainfall Seasonality
Region	Minimum	Maximum	Minimum	Maximum	
Dry tropical	0	< 600	>= 15C		Summer
Moist tropical	>= 600	< 1,000	>= 15C		Summer
Humid tropical	>= 1,000		>= 15C		Summer
Dry subtropical	0	< 600	> 0C	< 15C	Summer
Moist subtropical	>= 600		> 0C	< 15C	Summer
Dry temperate		< 600		<= 10C	Summer
Moist temperate	>= 600			<= 10C	Summer
Alpine			Mean maximum temperature hottest month < 23C		Uniform
Cold desert		< 400		<= 11C	Uniform
Warm desert	0	< 250	–	–	Winter & Uniform
Mediterranean	>= 250		–	–	Winter & Uniform
Maritime	>= 400		>= 10C		Uniform

- Localized differences (e.g., altitude, topography, ocean, cloud cover) have major influences on the previous two assumptions, e.g., local differences in altitude have an inverse effect on temperature.
- Effectiveness of rainfall is influenced by season of occurrence, intensity, slope, soil cover and soil physical characteristics.
- Many temperate annuals can be grown under irrigation during winter (established in autumn) in subtropical and tropical summer rainfall regions.

The International Laboratory for Research into Animal Diseases (ILRAD) of Nairobi, Kenya in association with the Australian National University have created a grid-based, five-kilometer resolution, monthly mean climate database for the entire African continent. The climate variables include precipitation, temperature and evaporation. The variables were derived through spatial interpolation of longitude, latitude, and elevation to distributed climate recording stations found throughout the continent. The mean annual precipitation, temperature of the coldest month (July), temperature of the hottest month (January), and a rainfall seasonality surfaces were used with the rules presented in Table 4 to produce the agroecological zonation system map in Figure 1.

However, the different countries involved in the study adopt different agroecological zonation schemes. Because researchers and policy makers in each country are familiar with the existing zonation system, country research teams are advised to follow the following recommendations:

a. Adopt existing versions of the zonation schemes to design surveys and conduct data collection and analysis.

b. When digital versions of the existing zonation system don't exist, available hard copies of the zonation scheme should be digitized. This will make the generated data and results of the analysis readily integrable with other spatial data into one digital data base.

c. When no zonation scheme exists, adopt the generalized agroecological classification developed in this document and provided as part of the country digital data base installed by the project.

The power of GIS is the ability to transfer data from one spatial coverage to another with ease. This makes the integration of all of the country's data and results into a single standardized zonation scheme for conducting further analysis at the regional scale.

B. Missing Data on Production Potential and Crop Growth Simulation Models.

In many countries data is very scarce on actual and potential yield levels. Average yield data obtained from surveys of groups of farmers or from aggregate national statistics, are usually adopted as estimates of current practices. It is, however, very rare that such average production data are adequately categorized by environment. On the other hand, only point data collected from experimental research trials on limited number of sites is usually available to characterize production potentials. In many cases even such limited experimental records are not available. Crop growth simulation models and grid-based spatial analysis tools can be employed to model the missing data. Relevant grid-based climate data manipulated using generalized crop potential yield models can be used to provide a spatial potential yield surface of an entire country or region. Actual or potential production parameters can then be generated and properly characterized by environment as well as by any other spatial attribute. An example is described below for such an application for SA.

For this project a simple dryland maize yield estimation model was used to create a spatial surface of potential yield for the whole region (Smith 1996). The simple yield model is only an indicator to identify areas and specific sites where maize can be grown successfully. The model is based on the following parameters that were modeled in a grid-based GIS using the same climate data as used to develop the agroecological zonation scheme. Yields of dryland maize can be estimated by using rainfall, heat units, soil types and management.

Rainfall

For good yields a dryland maize crop requires 500 to 700 mm of rain over the growing season (October to March), which is approximately 80 percent of the mean annual rainfall. The effectiveness of the mean annual rainfall in excess of 1000 mm is considered to be reduced progressively for summer crop production, as it would tend to exceed the evapotranspiration. The effective rainfall is also assumed to decrease with decreasing rainfall.

Heat units

For germination the optimum mean daily temperature is between 18^0 and 20^0 C. Optimum temperatures for growth are between 24^0 and 30^0 C with a range of 15^0 to 35^0 C. Growth is inhibited below 10^0 C and above 30^0 C. Subtracting 10^0C from the mean daily temperature will give the number of Heat Units for that day and maize requires at least 1,500 of these units to achieve an optimum yield during the growing season. Less than 1,500 heat units would depress yields and from 1,500 up to about 1,800 heat units would result in increased yields. Over 1800 heat units would tend to suppress yields due to high temperatures and less effective rainfall. Heat units should be at least 750 up to tasseling, or the average January temperature should exceed 19^0 C. Hot humid conditions are not suitable because of the occurrence of disease. Instead of using the mean daily temperature, GIS data on the mean monthly temperature was used to develop the Heat Units surface for the October to March growing season.

Soils

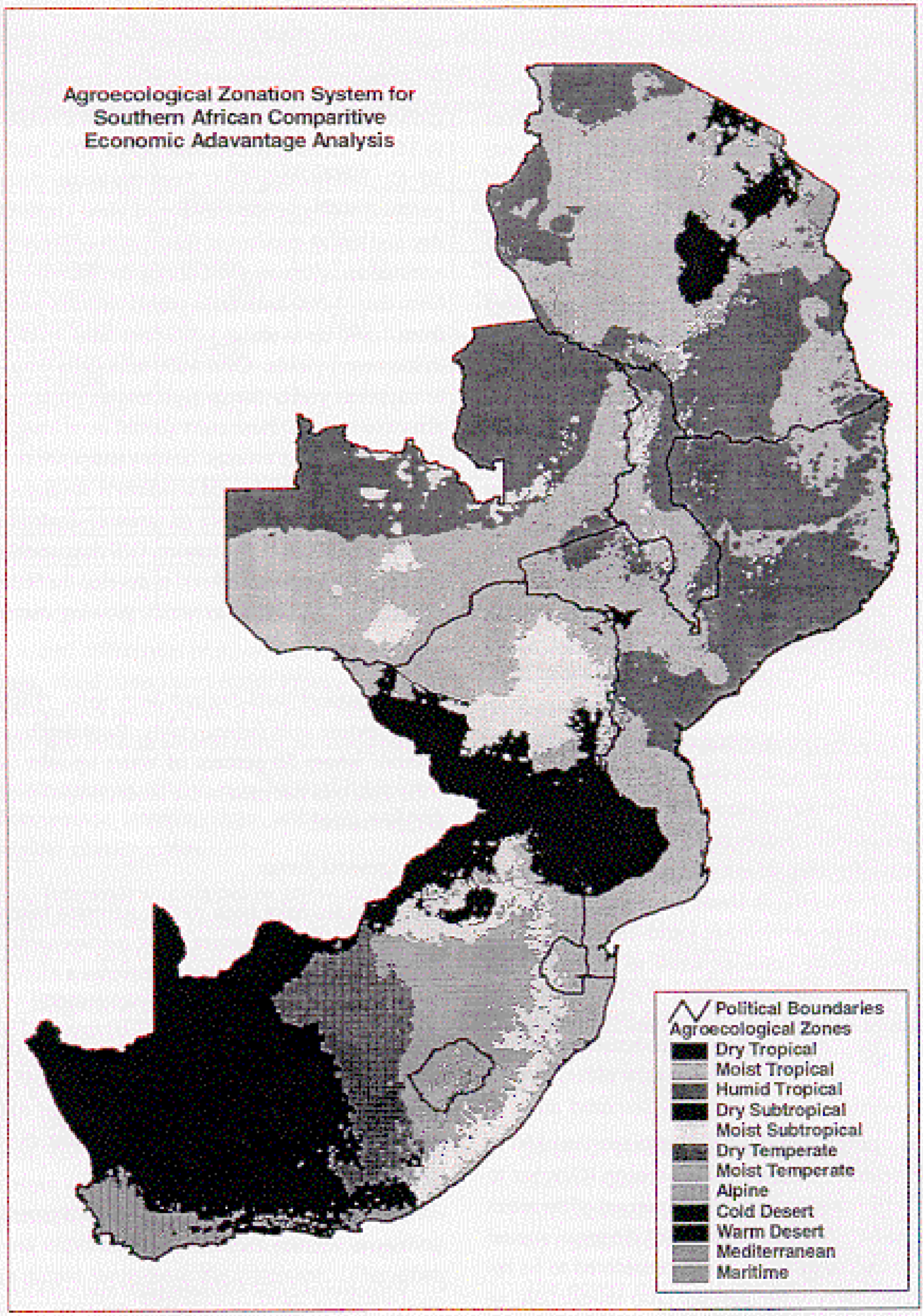
Maize requires well-drained deep soils. Light and heavy texture soils reduce yields. Root depth is about 900mm where 80 percent of water up-take occurs. Soils data was not used in the model output presented in this manual.

Management factor

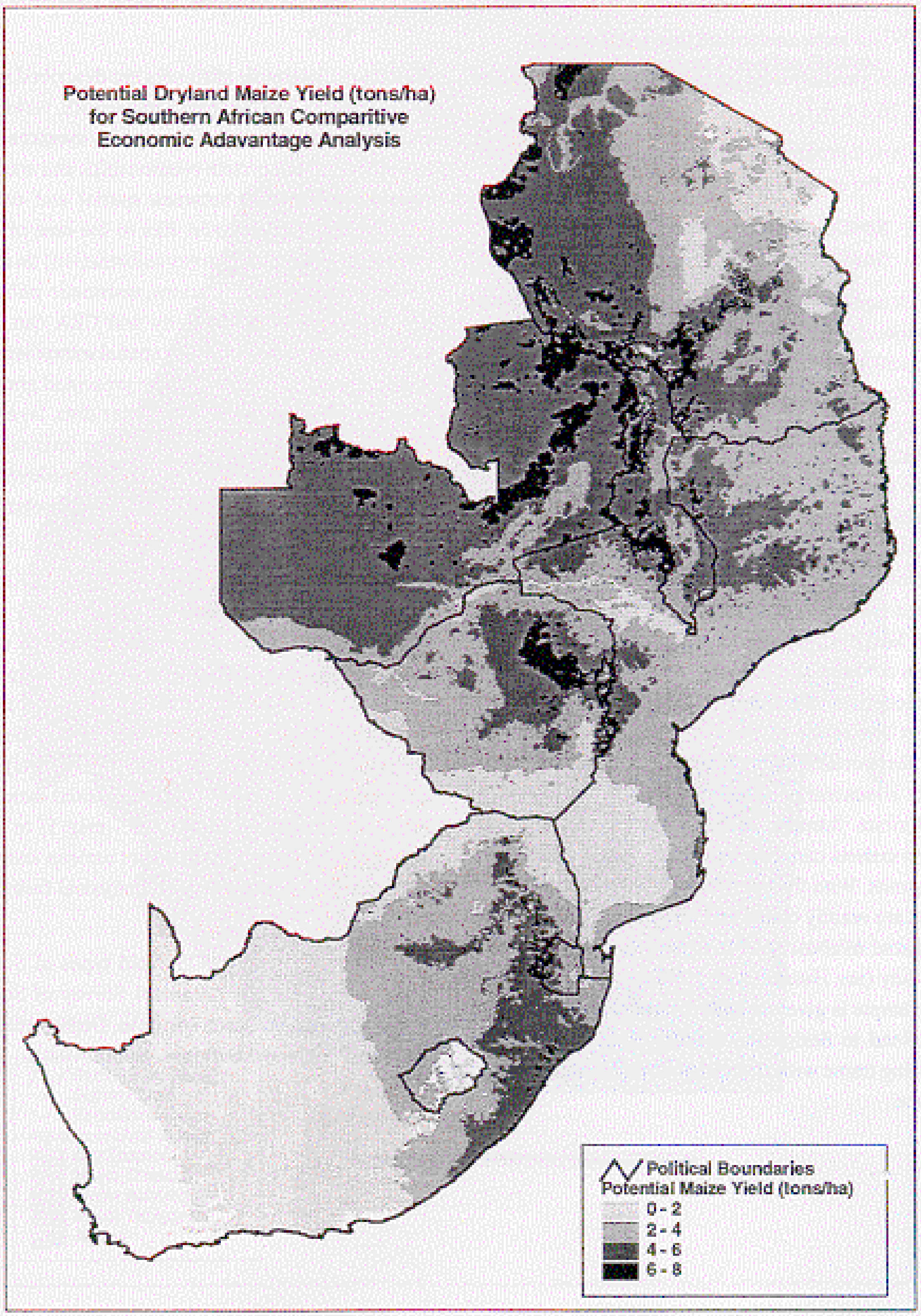
The estimates have been further adjusted based on a *good* level of management. The management factor tends to suppress yields, but it provides a more realistic picture of the potential yields of a region.

The following example illustrates how dryland maize yield potential was calculated using GIS. In an area with an October to March rainfall of 680 mm and 1800 heat units with good management, the maize yield could be estimated as follows:

- Rainfall during cropping season 680 mm, (October to March).
- Effective rainfall 578 mm, (680 mm x 0.85) (based on simple regression).
- Heat units 1x800 resulting in 1.4 tons maize per 100 mm of effective rainfall per ha (based on simple regression).


Agroecological Zonation System for
Southern African Comparitive
Economic Adavantage Analysis
Political Boundaries
Agroecological Zones
Dry Tropical
Moist Tropical
Humid Tropical
Dry Subtropical
Moist Subtropical
Dry Temperate
Moist Temperate
Alpine
Cold Desert
Warm Desert
Mediterranean
Maritime

Map 1


Potential Dryland Maize Yield (tons/ha)
for Southern African Comparitive
Economic Adavantage Analysis
Political Boundaries
Potential Maize Yield (tons/ha)
0 - 2
2 - 4
4 - 6
6 - 8

Map 2

- Expected yield 8.1 tons/ha (578 mm x 1.4 tons / 100).
- Grain yield adjusted for good management 5.6 ton/ ha (8.1 x 0.7).

Figure 2 presents the final potential dryland maize yield for the study region.

C. Spatial Sampling and Integration of Survey Data.

Data on agricultural production and services, as well as socioeconomic characteristics of farming and farmers' practices are usually collected from field surveys. Such data are often analyzed with no reference to their spatial origins and circumstances. Important correlations between key spatial phenomena influencing the generation of these data and survey measures are accordingly lost as survey data analysis is divorced from its spatial context. GIS provides the tools for more meaningful and effective design of spatially referenced surveys and data capture. A spatial sampling frame based on proper stratification of target information domains and sources according to spatial and socioeconomic attributes of direct relevance to the subject and scope of the study can be easily developed for more objective selection of sites and for efficient allocation of sampling densities among delineated strata. Random spatial searches and other selection criteria can then be used to locate target sampling units. With the use of GPS devices selected data points are readily coded and integrated into the original spatial database used to stratify the population under study (see Hassan et al. 1998 for further details). An example is given in Map 3 from an application in Swaziland to design the country study surveys and sampling frame with an overlay on a climatic zonation scheme.

D. Spatial Analysis of Key Determinants of CEA

As data on economic attributes are described spatially and integrated into the spatial framework, various types of analysis can be applied to explain, measure and test hypothesis about certain relationships and spatial patterns of association between spatial and economic phenomena. For instance, like in the case of climate attributes, point data (survey information) on any economic variable such as prices, economic policy indices, measures of productivity and CEA can be converted into coverages through spatial interpolation. The resulting coverages can then be presented graphically as a map or combined with other data layers (e.g., climate, population, etc.) for further analysis. Techniques of spatial correlation can be employed to explain and measure various types of interrelations between economic and spatial variables.

As an aspect of direct relevance to CEA, especially in relation to transport costs, spatial analysis was applied to point data (settlements) to create a coverage showing distance from ports (as points of entry and exit of goods for trade). The generated map (map 4) can be used for calculating transport costs on basis of distance to trading points (ports), or can be combined with other layers of spatial data such as transport network (road and rail - map 5) or production potential (map 2) to conduct various analyses on the impact of economic and biophysical factors taken together on CEA.

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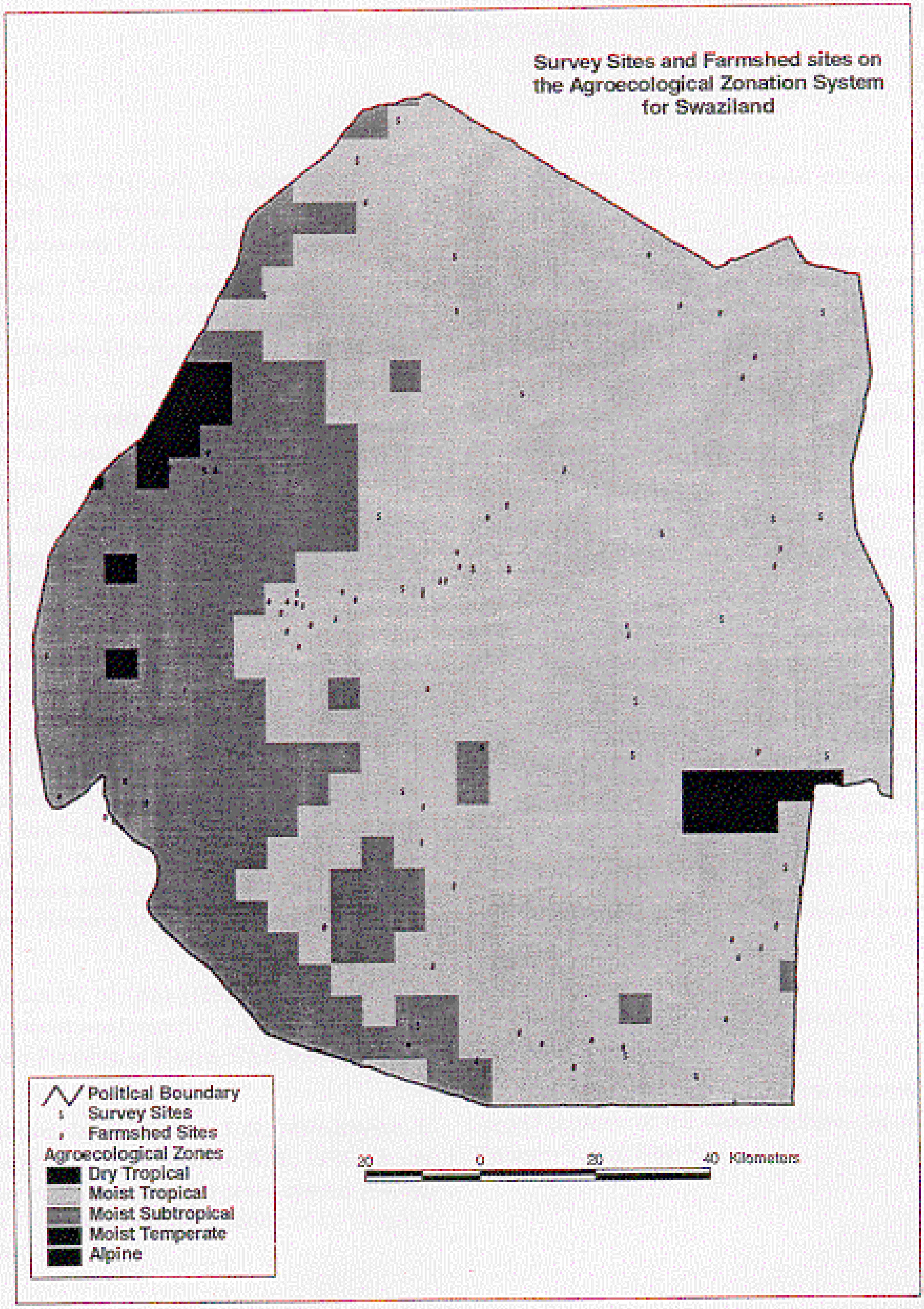
Survey Sites and Farmshed sites on
the Agroecological Zonation System
for Swaziland
Political Boundary
Survey Sites
Farmshed Sites
Agroecological Zones
Dry Tropical
Moist Tropical
Moist Subtropical
Moist Temperate
Alpine
20
0
20
40 Kilometers

Map 3

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Appendix 1

Project Support to Country-Level Capacity to Use and Apply GIS Tools

In support of basic capacity in country research teams to utilize techniques of spatial analysis and GIS, the regional project provided the following:

a. Hardware/software. The GIS software supplied and installed in all countries was the vector based ARCVIEW GIS 3.0.

b. A digital spatial database has been developed for every country (from contributions by WRI and CSIR) to support GIS applications. The digital database developed and installed in all case study countries contained:

   i. Climate data (mean annual precipitation and mean annual temperature)

   ii. Agroecological zones map

   iii. Maize production potential map

   iv. Infrastructure (road and rail networks, utilities, airports)

   v. Population distribution

   vi. River networks and wetlands

   vii. Protected areas (parks, forests)

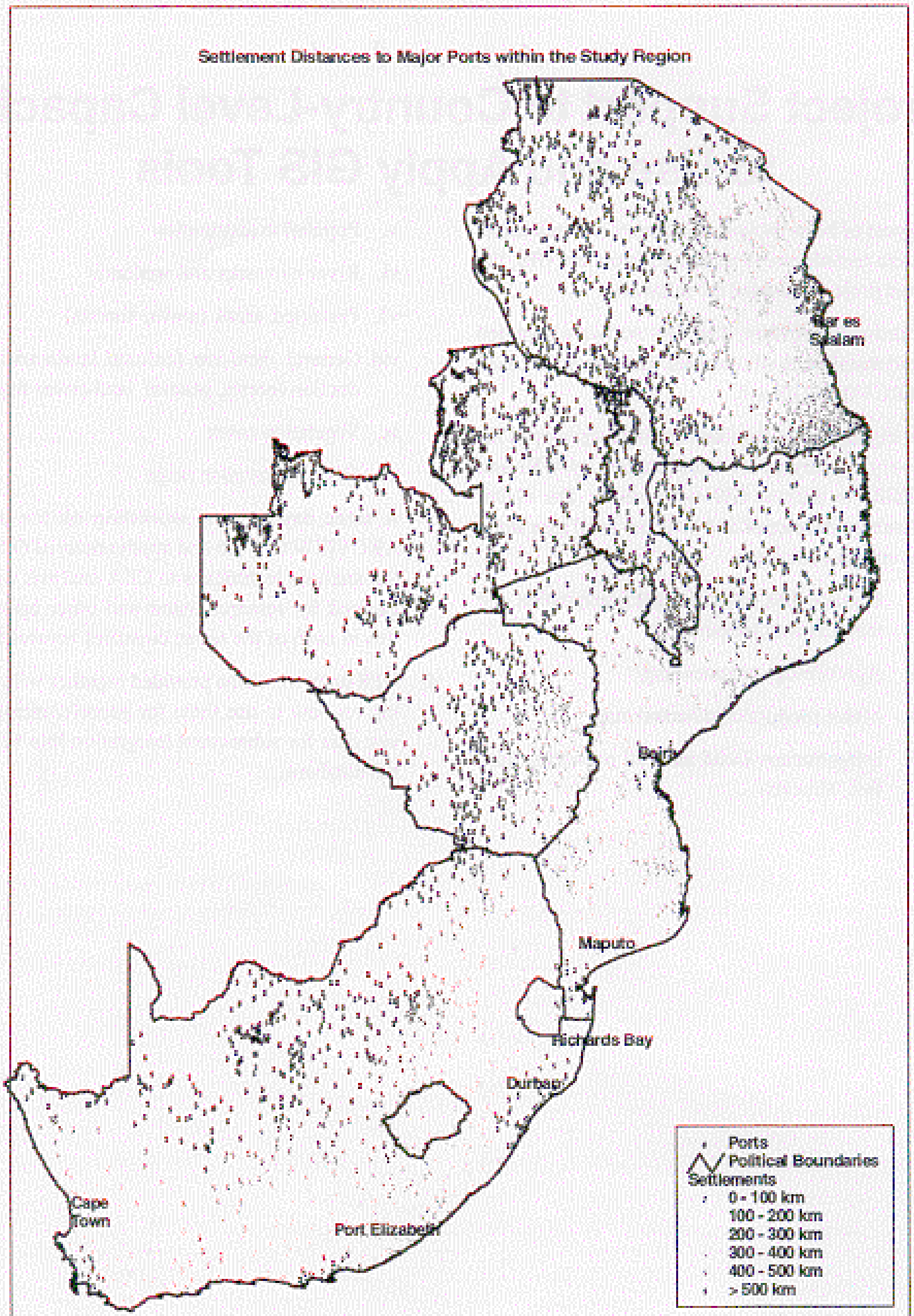
   viii. General land-use (cultural landmarks, production forests, general land-cover features)

   ix. Vegetation cover

   x. General elevation range

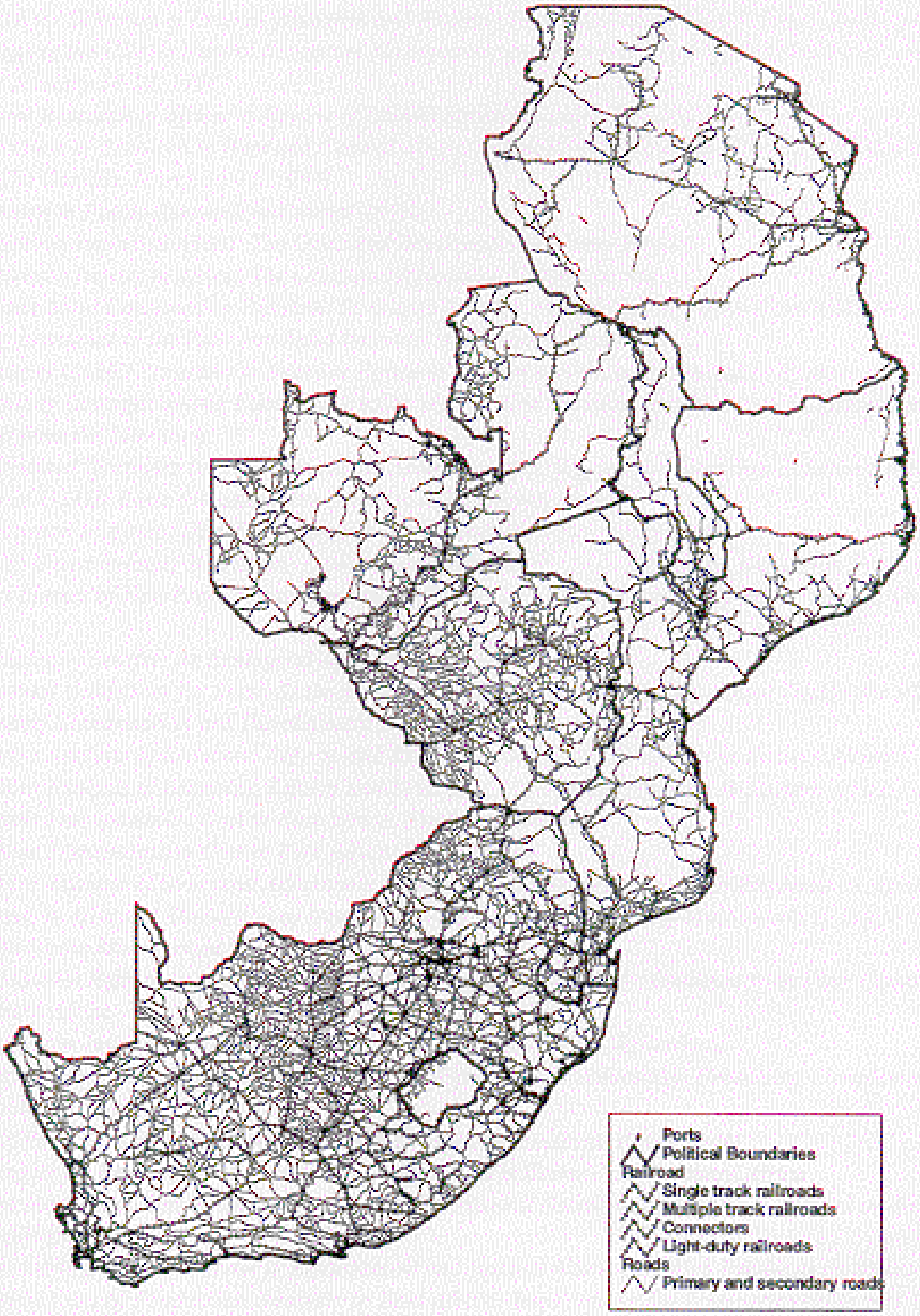
c. A three day training workshop on the use of ARCVIEW GIS 3.0 and applications of GIS spatial analysis techniques to CEA analysis was organized for research teams and other beneficiaries in each of the seven countries involved.

d. GPS units were also provided together with training on how to use them for georeferencing survey data for subsequent integration into the spatial database.


Settlement Distances to Major Ports within the Study Region
Dar es Salaam
Beira
Maputo
Richards Bay
Durban
Cape Town
Port Elizabeth
Ports
Political Boundaries
Settlements
0 - 100 km
100 - 200 km
200 - 300 km
300 - 400 km
400 - 500 km
> 500 km

Map 4

Road and Railroad Infrastructure within the Study Area



Map 5